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Risk governance in the megacity Mumbai/India – A Complex Adaptive System perspective

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1. Introduction: megacities as risk areas with complex multi-stakeholder environments

In the last decades, social and natural scientists have worked towards an improved understanding of disasters and risks. This has increased the understanding of natural hazards, which can – but not necessarily have to – cause disasters, as well as it has built up knowledge on vulnerability and the social dimension of risk. Increasingly, social scientists have drawn attention to the fact that every disaster is the result of the societal embedding in which a hazardous event occurs (White, 1974). To illustrate this: an earthquake in the desert, neither affecting any infrastructure nor harming any person, does not cause a disaster. It is the exposure of humans and of human-made infrastructure to hazards, which can result in a disaster if several factors add up.

This exposure to or rather the likelihood of people, infrastructure and built property being affected by a hazard is called risk, while a disaster, according to UNISDR (2009), can be defined as a disruption that makes external help necessary. In addition to this very simple definition, disasters are characterized by being caused by rare events, occurring in low frequency having a high amplitude. Finally, the causation of disasters is usually complex, extending well beyond the actual trigger event. Spatial knowledge of structures, processes and actors that shape disasters, and their impacts on communities, can help to improve risk governance and to design adequate disaster management measures.

The vulnerability against extreme events differs significantly between nations of different income levels. As Khan (2005) illustrates in his comparison of 73 nations, the number of fatalities from natural disasters is not related to the exposure towards extreme events but depends on the strength of the institutional set up. With the institutional set up being generally weaker in low- and middle-income countries, even simple and cost effective measures are often not applied there (Kenny 2012). Therefore, extreme events have a higher direct impact in low- and middle-income countries in terms of tangible and intangible losses and in many cases they disrupt the development paths of specific population groups (usually the poor) or whole regions.

Considered against this background, disasters in megacities of low- and middle-income countries (LMIC) justly receive growing attention in the risk and disaster research community amidst the wake of the global urbanisation process. In our now predominantly urban world the urban population is predicted to increase from 3.9 billion in 2014 to 6.3 billion by 2050 (UNDESA, 2014a: 20). This urban growth will almost entirely take place in low- and middle-income countries. In these, also the majority of megacities (larger than 10 million inhabitants) are and will be located. In 2014, megacities were home to 12% of the world's urban population and their number is predicted to increase from 28 in 2014 to 41 in 2030 (UNDESA, 2014a: 13).

As extreme products of current global urbanization processes, megacities of the LMIC are characterized by „increasing socio-economic vulnerability due to increasing poverty, socio-spatial and political-institutional fragmentation and often extreme forms of segregation, disparities, and conflicts“ (Kraas, 2007: 80). Thus, megacities of the LMIC as important nodes in the networks of the globalising world in can be addressed as “global risk areas” (Kraas, 2003: 10) with a much greater vulnerability than those of the megacities in high income countries (Wenzel, Bendimerad, & Sina, 2007). This characterization points to the fact that megacities of the LMIC are characterized by a hitherto unknown level of complexity (e.g. Parker, 1995; Kopfmüller, Lehn, & Nuissl, 2009) which may have serious implications in the risk and disaster context, as we will exemplify for the case of Mumbai in detail.

The analysis of the various factors that caused disasters in the past can help to sharpen the perception for the complex causation of disasters and enables decision makers to identify relevant

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information for increasing resilience and responding to hazards more adequately in the future. Our guiding research question is therefore: Does the application of a Complex Adaptive System perspective help to improve mega-urban risk governance and disaster management?

The paper is structured in the following way. First, it critically discusses an analytical framework for Complex Adaptive Systems in relation to the following questions: Which factors produce risk in complex mega-urban systems and how are they related? Which structures, processes and actors are involved in coping with mega-urban risks, disasters, crisis and conflicts? What are possible ways for dealing with the complexity of multi-stakeholder environments in mega-urban areas?

Second, in the empirical section the 2005 flood events in Mumbai/India will be described. In addition to the actual flood event, the change of risk governance and disaster management following the disaster (the reorganization of the system) is illustrated. These findings are based on empirical fieldwork in 2009 and 2010.

In the discussion we will interpret the empirical findings of the case study against the background of the theoretical framework. The potential of spatial knowledge for improving risk governance and designing disaster management in a megacity, understood as a Complex Adaptive System, will be discussed. In the conclusion, we will look at lessons learned from the Mumbai case study and point out the added value of a systems theory perspective on mega-urban risk and disasters.

2. A Complex Adaptive System (CAS) perspective on mega-urban risk and disasters

The megacities of the LMIC are exposed to a number of risks. First, they are often located in areas highly exposed to hazards (e.g. due to the proximity to coastlines or tectonic fault lines, climate zones etc.). Second, risks in these cities are shaped by the diverse internal social, political, economic, ecological and cultural processes, which interfere with and influence each other, as well as by the accumulation of critical urban infrastructure. As the formal economy of these agglomerations often does not grow in the same pace as the population, informality and informal dynamics are no exemption. This affects all aspects of life, and the resulting loss of governability leads to an increase in disaster vulnerability. The gradient of vulnerability of the population is closely related to socioeconomic disparities, with the poorest usually being most vulnerable (Kraas, 2003, 2007).

Yet, megacities are not only places of high risk but also of high potential and some aspects of informality can also turn out to be assets in regard to disaster risk reduction or disaster response: Informal networks, often hindering planned development, reinforcing path dependencies and sometimes decreasing efficiency, have proven to be important means of first response during disasters (cf. section three). Megacities' positions within their respective national economies, their connection to global networks and the accumulation of resources (knowledge, capital, political power) enables them to recover from disasters fast on a systemic level, inter alia because they can often effectively raise external help quickly, if necessary. Besides formal mechanisms of disaster relief, informal structures can in many cases also be regarded as an asset. Since social networks and local self-organization processes are means of managing everyday life, they also complement or even substitute official structures in disaster management as a specific aspect of life – and sometimes they even do so more quickly (Kraas, 2012; Wisner, 2003).

Complexity, informality, vulnerability, resilience and risk thus are aspects, which are closely connected in the context of mega-urban disasters. Elsewhere we have argued, that the interactions between various factors turning an event or hazard into a disaster can be understood better if a system perspective is applied (Peters et al. 2015). In this understanding, megacities are framed as Complex Adaptive Systems (CAS) characterized by the three axioms of chaos-theory. 1) The dynamics of these systems is unforeseeable due to the high number of inter-linkages and feedback-mechanisms. 2) Minimal changes can trigger maximum changes. 3) Such dynamic systems will start to produce stable patterns and structures if the external influences (e.g. inflow of energy and matter) remain unchanged. The complexity of CAS emerges from the unexpected dynamics characterizing these systems. These dynamics are the result of the nonlinear interactions between the systems' elements, which lead to self-reinforcing or self-moderating processes (Norberg & Cumming, 2008).

One additional distinct feature of CAS is co-evolution (Kauffmann 1990). In cities, this means that physical infrastructure and social structures are influencing each other and certain processes are reinforcing each other through the creation of path dependencies, which are bound to different types of infrastructure. But co-evolution in a human-made system also means, that there is the possibility to guide this co-evolution and adapt it to counteract new risks. Unfortunately, in a CAS co-evolution makes it impossible to foresee all possible developments. In the panarchical perspective (panarchy being the antithesis to hierarchy, meaning that small changes in subsystems have the potential to cause disproportional disturbance at higher system levels), any element in the system can potentially trigger changes that can ultimately affect the system as a whole (Gunderson & Holling, 2002).

In the context of urban research, especially dealing with disasters in urban areas, this understanding of systems can provide new perspectives. It allows for describing actual urban dynamics, which are not aiming at an equilibrium state but produce imbalances at various levels (inflow and discharge of matter, but also social inequities and power-imbalances) and are governed by a mix of formal and informal institutions. The latter poses a severe challenge, since the transfer of knowledge between formal and informal institution often does not take place. These distinct features of CAS seem to be well suited for applying a systemic perspective on cities in the risk governance context. The general applicability of system theory for understanding risk governance has been principally proven by other scholars who have conceptualised cities as Social-Ecological Systems (SES). Especially flood events have been successfully analysed from this perspective (e.g. Birkmann, Garschagen, Kraas, & Quang, 2010; Pahl-Wostl, 2007). The SES perspective is closely related to the CAS perspective but focuses more on the assessment of vulnerability and resilience. This strand of research is especially investigating how society and environment interact in coupled systems, how ecosystem services are produced and consumed and how this affects system dynamics and the amount of change these systems can undergo and still provide adequate ecosystem services (Adger, Hughes, Folke, Carpenter, & Rockström, 2005).

Going beyond the earlier conceptualisations of cities as socio-ecological systems, we have developed a framework that allows for an analytic perspective on risk and disasters in megacities (cf. Fig. 1; in more detail cf. Peters et al. 2015). The visualisation was developed to illustrate how the megaurbanmega-urban disaster concept can be framed from a CAS perspective. Yet, we can of course not map complexity realistically but only hint at the multiple connections. As such the strength of the CAS approach is its ability to simplify complexity. This allows for a transfer of this approach to the political sphere (Welsh, 2013).

The framework puts disaster in the centre of the analysis and aims at explaining its genesis and its consequences, thereby focussing on knowledge and management aspects of disasters. The disaster itself marks in a temporal perspective the turning point between risk governance and disaster response and recovery, which is also reflected in the framework: The upper sphere is a visualization of the risk governance aspect, our (spatial) knowledge about the formation of a disaster. It shows various mediate (secondary, tertiary etc.) and immediate (primary) risk factors that shape the environment in which a hazard can actually trigger a disaster. What is crucial in this perspective is that not only the immediate factors are taken into consideration, but also mediate factors of first and secondary order. Ideally, this perspective allows for understanding the underlying root causes of disasters. Accordingly, the lower sphere in the framework shows the multiple and sometimes long-term effects of disasters. These are direct (primary) effects and further effects triggered by these primary effects themselves, but also new risks that arise in the disaster situation. We therefore distinguish between 1) direct and indirect effects, 2) risk chains and 3) risk cascades. Risk chains emerge when the direct effects of a disaster constitute new hazards through linear pathways while risk cascades are also triggered by the effects of the disaster but unfold through multiple and complex pathways in a non-linear fashion (for a more detailed description cf. Peters et al. 2015).

What is unique about this CAS perspective on risk and disaster is the holistic perspective, which points to the following aspects (Fig. 1): 1) the complex causation of disasters has to be considered in effective risk governance strategies, which – based on holistic analysis – aim not only at the triggering event and the primary influencing factors but also take root causes into consideration; 2) multiple interactions and reinforcing processes have to be taken into consideration in the causation of disasters and in disaster management; 3) besides the direct effects there are indirect long-term effects of disasters, which can be understood better from a systemic point of view; 4) for understanding risk in a complex

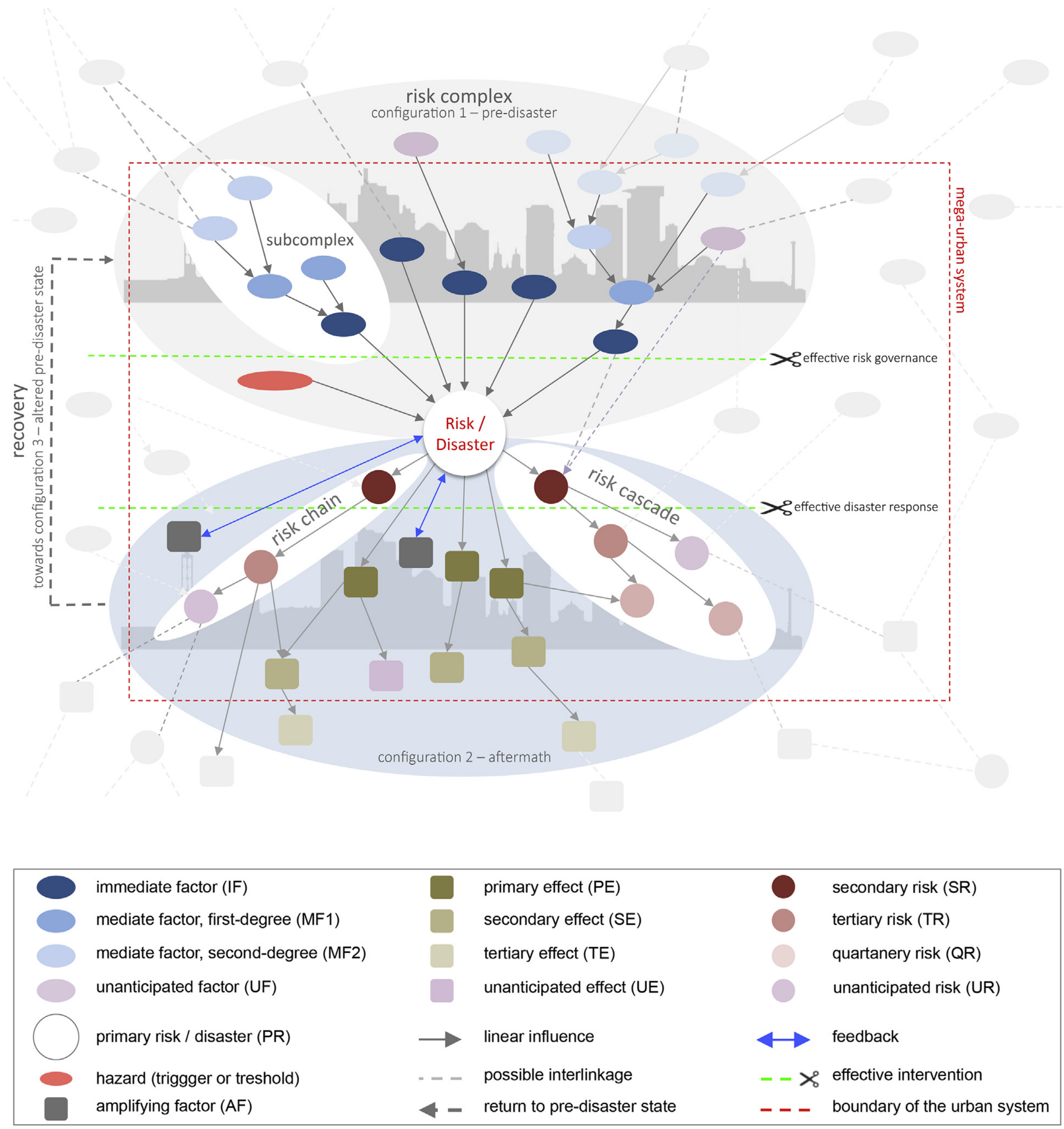

Fig. 1. Visualisation of a comprehensive, complex, holistic multi-stakeholder risk framework of a Complex Adaptive System (CAS).

socio-ecological system, like a megacity, different types of knowledge need to be combined, as the dominant scientific-technological approach, usually applied in risk governance, is inadequate to integrate social aspects; 5) combining different types of knowledge (institutional knowledge, scientific knowledge, experiential knowledge etc.) of the actual situation and past events are needed to understand mega-urban disaster risk complexes.

3. Understanding the complexity of flood risks in Mumbai, India

3.1. Local factors of flood risk

Flood risk in Mumbai is constituted by the city's location and its morphological structure. Mumbai is a costal city located in the tropical wet and dry climate zone (Aw in the Köppen climate classification). Between June and September the city receives 2500 mm of its annual precipitation of 2700 mm (de Sherbinin, Schiller, & Pulsipher, 2007: 46). The city's morphology, which has been crafted over centuries, contributes to the risk of flooding: Founded by the Portuguese as Bom Bahia (the „good bay") the site was controlled by the British from 1661 onwards, who connected the original seven islands into the peninsula that today is the centre of the urban agglomeration (Mumbai Metropolitan Area) with its more than 18 million inhabitants (in 2011[1]) (de Sherbinin, 2007). Many of the land reclamation areas are of low elevation, most of them situated only a few meters above sea level and some even below (Government of Maharashtra, 2006). Hardly any natural system of creeks or rivers exists in these parts of the city, which are traversed by an artificial system of canals built by the British. An additional factor, which significantly increases the flood risk is the massive degradation of natural vegetation: once mangroves served as a protection against flooding from the sea and the formerly thick forests in Salsette had a higher infiltration capacity than the current land use, resulting in a slower discharge (Srivastava & Mukherji 2005).

The human-made landscape of the city together with the climate therefore constitutes a certain exposure towards the risk of flooding. This risk is amplified by the way the city is governed: For instance, the underperformance of the municipal waste management system, which has led to huge quantities of waste being disposed off into rivers and canals by the population, has become a significant causative factor of blockages of the drainage system. Also, the lack of control of land use regulations and building standards has resulted in an increase in flood risk, since houses are built on river banks and flood plains. This results in a direct exposure to floods and a reduction of retention areas, which increases the severity of floods within the whole city. Secondary risks are related to the design of the city's critical infrastructure, especially the transport infrastructure. The airport is located in a flood prone area on the banks of Mithi River and several nullahs (creeks) cross the airport area. The suburban railroad traffic, the city's lifeline, which is used by two to three million commuters daily to get to the city centre in the South of the peninsula, is collapsing partially during heavy rainfalls, affecting the livelihoods of millions and the functioning of the world city's economy.

The annual monsoon rainfall results in recurring inundation, putting severe strains on livelihoods (de Sherbinin et al. 2007) and increasing gastrointestinal and vector borne diseases. Small areas are flooded regularly with 0.5–1.5 m of water (Gupta, 2009). These annual floods are by most people not perceived as disastrous situations: „[in] Bombay 10–20 cm is nothing, it is only when you have 60 cm, 80 cm, […] otherwise we can't call it a flood" (expert interview with the municipal corporation). However, this constantly recurring loss of assets and negative impacts on human health significantly increase the baseline vulnerability in the affected areas, especially in the slum settlements.

3.2. Material and methods

Two research areas were chosen that were affected by the 2005 flood in Mumbai: one consolidated slum settlement called Shastri Nagar and an inner city middle income area called Ashok Nagar (Map 1). Fieldwork was conducted in 2009 and 2010 to collect data on factors influencing the flood risk, general exposure towards hazards, effects of the 2005 flood, help and support networks for dealing with floods, changes in risk governance and socioeconomic characteristics of the households in the research areas. For the data collection in Mumbai a multi-method framework was applied. During the fieldwork, 17 expert interviews were conducted with representatives of the state government, the Municipal Corporation of Greater Mumbai (Brihanmumbai Mumbai Corporation – BMR), the Navi Mumbai Municipal Corporation (NMMC) and representatives from several NGOs and research institutions. In the two research areas participatory urban appraisal (PUA) methods, such as transects, cause-and-effect diagrams and Venn-diagrams, were combined with unstructured interviews, mapping and photographic documentation to explore the research areas. A household survey was undertaken in randomly selected households (99 in Shastri Nagar, 101 in Ashok Nagar). The survey consisted of different modules on the household structure, experiences with past flooding events and other types of disasters (health crisis, social unrest), housing structure and socioeconomic status of the household. To assess the latter, the availability of assets in the households was

Map 1. Location of the study areas in Mumbai (own design).

[1] http://www.census2011.co.in/census/city/365-mumbai.html.

recorded as second indicator for relative wealth/deprivation besides the monetary income. Following Butsch (2011: 128) the availability of 22 items was recorded. These items were given different scores in the analysis: one for basic items, two for technical equipment (mobile phone, water filtering system), three for advanced and expensive technical equipment (computer, land line phones, motorbikes) and four for car ownership. Based on this a wealth score was calculated for every household by summing up the score of the items present in the particular household. In total a maximum score of 41 could be achieved for the 22 items.

The standardized interviews were either undertaken in English or Marathi, supported by an interpreter. From the household sample 18 typical and extreme cases were selected for problem-centred interviews and as participants for focus group discussions. The household survey was analysed by descriptive statistical methods. The recordings of qualitative method conductions (PUA, expert interviews, problem-centred interviews, focus group discussions) were transcribed (and translated if necessary) and subjected to qualitative content analysis.

3.3. The 2005 flood event

In July 2005, Mumbai was affected by an extraordinary heavy and very local rainfall event. In the north of Mumbai (Santa Cruz), 944 mm of rainfall fell within 24 h, while in the south (Colaba) only 74 mm of rainfall were measured (Gupta, 2009: 241f.). The resulting areal flooding affected 22% of the whole area of the city (Government of Maharashtra, 2006: 15). Since the flood affected mostly the northern areas of the peninsula, the city centre in the south was affected indirectly, as it was almost completely cut off from the mainland. About 2 million people were unable to leave the downtown area due to the failure of transport infrastructure (especially the railroad network) and about 2.5 million people were trapped by inundation (Government of Maharashtra, 2006: 15). In total 450 people died in flash floods, landslides and the collapse of provisional buildings – especially in slum areas – and from electrocution (Government of Maharashtra, 2006: 247, Gupta, 2009). Secondary risks arose from the catastrophic hygienic conditions, the cut of power supply and the partial collapse of the fresh water supply and the communication system (expert interviews). This led inter alia to several waterborne diseases like hepatitis and gastro-intestinal infections, resulting in 248 additional deaths (Government of Maharashtra, 2006: 247, Gupta, 2009). In the wake of the flood an increase in vector-borne diseases was observable that can be linked to stagnant waters, which remained long after flood waters receded (Source: own interviews ExIMum0002, ExIMum0013a cf. references section, Gupta, 2009). Long-term health effects are expected because of the population's exposure towards chemicals like cyanide, which entered into the floodwater in high quantities when illegal small-scale industries were inundated, surpassing the concentration usually caused by illegal discharge (Ellenrieder, 2006). These events can be interpreted against the background of the framework developed in section two as risk chains (inundation – land slides – collapse of buildings) or as risk cascades (inundation resulting in a) vector breeding and b) pollution of the water, resulting in multiple negative health effects). For a better understanding and prediction of these risk chains and risk cascades, the application of a spatial perspective can be very valuable. Many secondary risks are actually the result of locational effects, e.g. the aforementioned discharge of chemicals into the floodwater arose from the chemical plants' location in flood prone areas. Therefore also spatial aspects – based on spatial knowledge – of linkages within CAS are important for understanding feedback mechanisms and amplifying factors.

The tangible damage of about 770 Million US $ of insured damage (and probably a multitude of this in uninsured damages) was the highest ever experienced in India till date (Ellenrieder, 2006: 40). Additionally, the state and municipality had to carry the costs of recovering the damaged infrastructure. On a higher scale, the national GDP was affected as the Mumbai stock exchange, India's leading financial centre, had to be closed: „If Mumbai stands still for a day, ok. But catastrophic impacts cause a tremendous problem for the national GDP. And therefore any hazard or any disaster in the city is not affordable for the national GDP“ (ExIMum0015).

Apart from official key actors in the disaster response, namely local authorities (municipal corporation staff, police, fire-fighters) and NGOs, most of the interviewed experts also highlighted the decisive role of the civil society during the 2005 flood: “So most people […] just walked home and then saw what all was in their house. You know you had one gunny-bag of rice. They just cooked the whole thing, as long as the gas lasted. If they had two liters of milk they made tea, if they had dhal they just cooked it, if they had vegetables they cooked the whole thing. Then they just brought out what they had and then everyone on the roads, stuck, just ate from it. They protected each others' properties“ (ExIMum0011b). This ”spirit of the Mumbaikars” (ExIMum0017) is believed by most to have contributed significantly to minimizing negative consequences and restoring essential functions in a quick and efficient manner. The experts mention especially the ingenuity, talent for improvisation, solution orientation and cohesion in the neighbourhoods as essential for coping with shocks on a small scale instead of relying on external help, which serves as an example for spatio-social construction of knowledge within the community. Thus, informal structures, actors, and processes are highly important in dealing with risk and have to be included in the knowledge that is generated and collected on risk.

3.4. Implications and perception of risk in Shastri Nagar and Ashok Nagar

The implications and perception of flood risk in general and the consequences of the 2005 flood were studied in detail in two selected research areas. Shastri Nagar is situated on the banks of the Mithi River. The approximately 1000 households are situated in one- or two-storey buildings on a plot of land of about 0.3 km^2, bordered by a light industry area. In most cases, the land is not owned by the inhabitants, but they rent it and construct the house, which they then own (83%, own survey). This so-called Pagadi system is typical for Mumbai where especially in informal settlements the land is owned by “slum lords” who rent plots of land to the tenants who are responsible for the construction and maintenance of buildings (Sheth, Velaga, & Price, 2009). Inside the settlement, there are several small shops and businesses. A few roads, accessible for small cars and rickshaws, traverse the area. However, most houses are only accessible via small alleys only suitable for pedestrians. Not all the houses are permanent structures; the roofs are mostly made from metal sheets and corrugated iron, some from wood; most walls are made from concrete and for three per cent mud or metal sheets are used. In respect to the flood risk, only 25% of the households have elevated entrances (own survey).

Not all the houses offer basic amenities: 25% of the surveyed households do not have a water tap in their house. The drainage system is based on open canals in the small alleys and often fresh water pipes are placed within these canals, resulting in regular contamination of fresh water. Since water is delivered by the municipal corporation, usually in morning hours only, the water pressure is low most of the day, so that wastewater enters the pipes through leakages, joints and fittings.

In the settlement, Muslims (55%) and Hindus (36%) live in

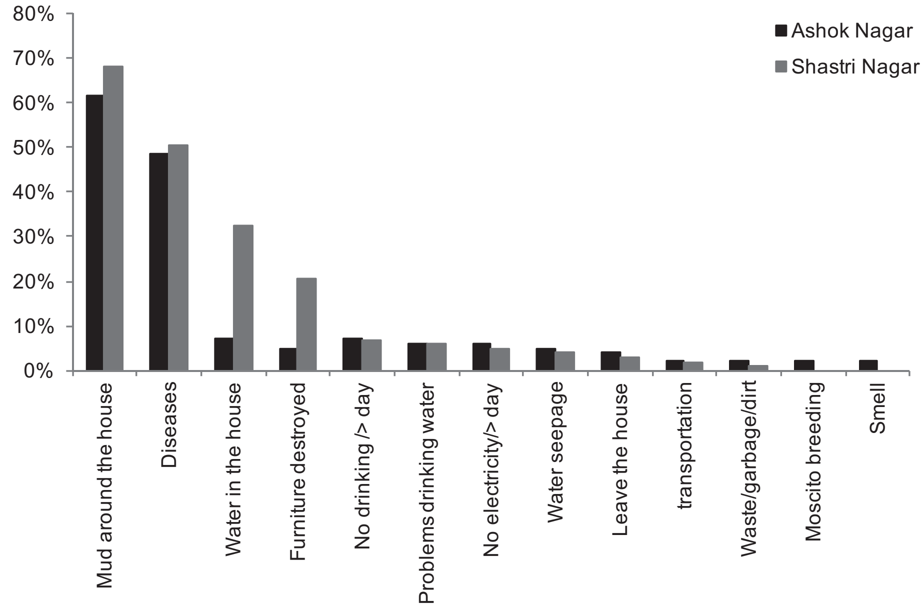

Fig. 2. Effects of annual flood events in Ashok Nagar and Shastri Nagar, own survey.

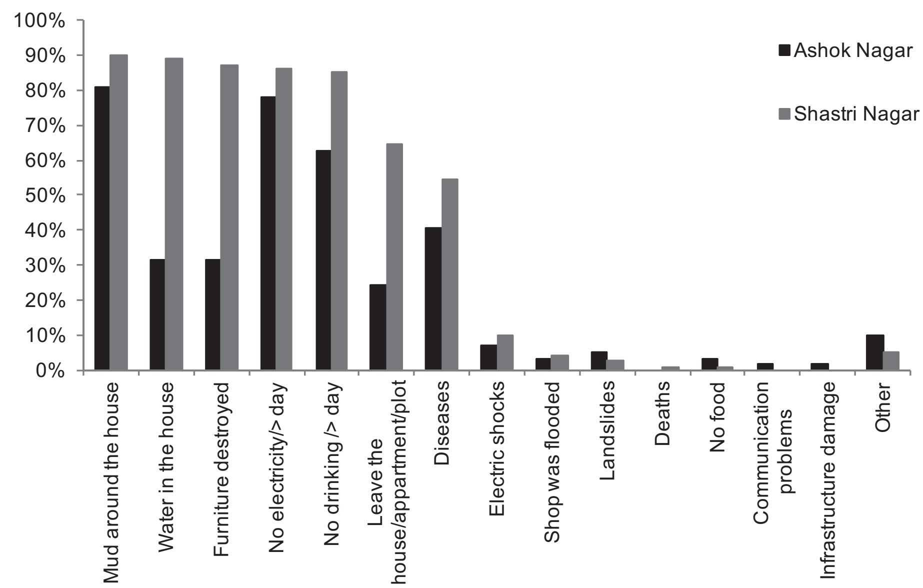

Fig. 3. Effects of the 2005 flood in Ashok Nagar and Shastri Nagar, own survey.

clearly separated areas (data in section stems from the own survey). The household size in the whole area is quite large: 49% of the households comprise six or more members. The demographic profile of the surveyed households indicates that the population is relatively young, with an average age of 27 years, while the sex ratio is in favour of male inhabitants (984 women/1000 men). About seven per cent of the households reported an income below the official poverty line of 665 INR per person per month.[2] Another 17% reported an income that was above the poverty line but less than double the amount of the official poverty line. In Shastri Nagar, the average score of the wealth index is 14.5, indicating that many households can hardly afford basic amenities (minimum: five, maximum: 31, standard deviation: 6.3).

The situation is quite different in Ashok Nagar: The average wealth index there is 25.3 (minimum: eight, maximum: 40, standard deviation: 8.5), indicating that many households cannot only well afford to cover all basic amenities but also have access to advanced technical equipment. This is also reflected in responses regarding the household income: Almost two thirds of the households (64.3%) have an income which is more than ten times higher than the official poverty line. Accordingly, basic amenities like piped water and toilets can be found in every house. This typical middle class area is situated in Santa Cruz East, South of the Air India Colony. The area covers roughly 0.4 km^2 and hosts mainly multi-storey buildings and few single-family houses. These are all

[2] State Specific Poverty Line defined by the Planning Commission for Urban Maharashtra 2005-05 accessible at http://planningcommission.gov.in/news/prmar07.pdf (accessed 11-Febr-2015); equals 10.71 $US on February 15th 2015.

pucca structures (solid built) and most of the multi-storey houses are cooperative housing societies, some of which were constructed as slum rehabilitation measures. During the time of the household survey there was a lot of on-going construction work, several new multi-storey houses (up to 20 floors) were being built. The area was exclusively used for housing. However, on the ground floors of some houses there were shops and businesses, and medical clinics. Regarding the exposure to floods, often the ground floor was not used for housing in multi-storey buildings.

The household size is significantly smaller: 69% of the households have between three to five members and five per cent are single households. While 89% own the house in which they live, 11% live in rented accommodation. In total there are fewer younger persons living here and the average age is 34. The gender ratio is even more in favour of the male inhabitants (955 women/1000 men). 79% of the surveyed households in this area are Hindus, nine per cent Christians, six per cent Jains, five per cent Muslims and one per cent Buddhists.

In Ashok Nagar there is a central canal of about 10 m in width. It is a tributary of the Mithi river. This canal is often jammed because it is regularly used as a site for waste disposal. This canal is decisive for the exposure of the area towards flood risk.

Both of the study areas are affected by annual flooding events during the monsoon period. In Ashok Nagar, 92% of the respondents in the household survey said, that their neighbourhood is affected by inundation during the monsoon, in Shastri Nagar the share was 97%. However, these are mostly singular events. In Ashok Nagar 75% of the respondents said, that their neighbourhood is affected only once a year, in Shastri Nagar 80% said so. These annual flood events have different effects in the two research areas, related to differences in housing structures (Fig. 2). As most of the slum homes have their entrance and living room on the ground floor, they are directly exposed to the primary effects of inundation events. One third of the respondents said, that water enters their house regularly and 21% reported that furniture is thereby destroyed. This is different in the middle class area, where most respondents reside in multi-storey buildings. Only seven per cent reported water in the house during monsoonal flooding and only 5% reported destroyed furniture. In both areas, the majority of respondents reported that there is an accumulation of mud around their houses and 50% of all respondents indicated an increase of diseases during or shortly after these flood events. Especially the rise of malaria is attributed to the annual floods.

In both areas, the effects of the 2005 flood were more severe than those of earlier events. In Ashok Nagar, 91% of the households reported that they were affected by the 2005 flood, in Shastri Nagar 97%. In Shastri Nagar, 89% of the respondents reported, that water entered in their house, 87% indicated that furniture was destroyed and almost two thirds had to leave the house because there was no electricity or drinking water available (Fig. 3). One of the households also reported a fatality. The flood affected the livelihoods of the respondents: In Shastri Nagar four per cent and in Ashok Nagar three per cent said that their shops were flooded. The relatively high share of respondents mentioning diseases as an effect of the flood event can be interpreted as the outcome of a risk chain, which was triggered by the disaster. In Ashok Nagar not only the primary effects were less (31% reported water in the house and destroyed furniture, 24% had to leave their houses), but also the secondary effects of the disaster were fewer. This holds also true for the cost of recovery from the disaster. In Ashok Nagar 48% of the households said that they did not face any cost and only 27% reported relatively high costs of recovery, exceeding 50,000 INR. In Shastri Nagar, 49% of the households said that the costs of recovery exceeded 50,000 INR, five per cent said that they could not name the amount they spent and the rest reported relatively large sums (16%: between 10,000 INR and 30,000 INR; 23%: 30,000 INR to 50,000 INR).

With hardly any household insured in both areas (zero per cent in Shastri Nagar, ten per cent in Ashok Nagar), the cost of the disaster had a negative long-term effect. However, there was a state funded compensation scheme, which provided 5,000 INR as a compensation for affected households. In Shastri Nagar 84% of the households reported having received this compensation, in Ashok Nagar 25% of all households have received monetary compensation for their loss, some even exceeding those 5,000 INR paid by the government if they were insured.

3.5. *Risk governance: responses, support and local engagement*

The information policy and flood warning by the authorities was assessed quite negatively. Only two respondents in Ashok Nagar said that they were warned before the flood struck their neighbourhood, while in Shastri Nagar all respondents said that the flood reached them unprepared. This is partly related to the fact that several communication systems failed during the 2005 flood event. Experts said, that landline telephones did not work in most of the affected areas, even satellite communication (for the emergency response forces) was not possible. Several experts reported problems with mobile communication systems (ExIMum0002, ExIMum0003). One expert summarized: „It was like everyone was lost. But worst was the loss of communication [...] We could not say what was happening where and how" (ExIMum0003).

Due to these problems, the municipal and state disaster management forces were hardly able to respond immediately and in a coordinated manor. After being asked who helped them during the flood one interviewee said: „No one, we were sitting here only". Instead, informal social networks were the most important and immediate means in disaster response. In Shastri Nagar 52% said[3] that they received help from their neighbours during the flood, 51% from their family or friends (quantitative data in this section stems from the household survey). Help from local authorities (one per cent), the military (three per cent) and the local ward officers (three per cent) were of minor importance compared to that. In total 26% of the respondents said that they did not receive any help. In Ashok Nagar, this share was a little higher at 37%. Here, neighbours were also the most important source of immediate help at 46%, followed by 37% who received help from their family or friends. Also local authorities (two per cent) the military (zero per cent) and local ward officers (zero per cent) were not perceived as sources of immediate disaster relief.

In the days and weeks following the flood, the two areas received attention from different actors. In Shastri Nagar, one person reported: „ [During the flood] nobody helped. Help came after three to four days. After four days we got help: ten kg rice, ten liters kerosene". In Ashok Nagar, 62% of the respondents said, that they did not receive any help for recovering after the disaster, 19% underlined the help from their neighbours, 14% from family and friends. Interestingly, different external actors were involved in the disaster response measures, even if only few received help from them: local authorities (four per cent), NGOs (six per cent), ward officer (one per cent) and the local representative to the corporation council (corporator) (five per cent). In Shastri Nagar, the picture is completely different. Only nine per cent of the respondents said that they did not receive any help after the disaster. Friends and family were with 30% as important as neighbours (31%). However, massive engagement of other actors emerged: 60% said that political parties helped them to recover from the negative effects of the flood, 42% named the local authorities as institutions

[3] for this question multiple answers were possible.

involved in flood aid. Further, in Shastri Nagar the military was mentioned (seven per cent), NGOs (six per cent), ward officer (11%), the local corporator (24%).

3.6. Aftermath: back to normal?

The massive mobilization of disaster response forces by the state and other actors after the water receeded resulted in the city returning to „normal life“ quickly. The train services – the city's “life lines” – resumed on 28th July and returned to the normal schedule within one to four weeks. Stranded cars were cleaned off the streets within days, the power supply restored after the water receded, and the airport reopened after two days (Fact Finding Committee on Mumbai Floods 2006). However, there were numerous long-term consequences. In several cases those who were affected by the flood had difficulties to recover from the effects, as mentioned in a problem-centred interview in Shastri Nagar:

> “… and if it all gets messed up … I couldn't take it and it was very difficult to get back to normal … and settling things … because my father was the only one who was earning and getting back all the things … because right now everything you require in the house … and everything getting scattered … I don't have the words to explain. I still have the fear in me and you know it's very difficult to get back to your normal life” (PCIMum0002).

The individual development paths, especially of the affected poor households, were thus significantly disrupted, due to the loss of savings and assets, which they had accumulated over several years. Under the surface, the return to “normal life” therefore sometimes did not take place or only after a longer period of time.

At the city level, structural changes were initiated to reduce the impacts of flood events in the future. The municipal government set up a network of 30 automated rainfall-radar-stations, which now help to identify critical locations better and faster. Also the city's drainage network receives more attention and annual cleaning drives of the nullahs ensure their maximum discharge capacity. Several technical measures were put in place, such as flood walls, pump stations and emergency shelters. The prediction of rainfall events was increased by the installation of a Doppler Radar station. In addition, Mumbai changed the risk governance and disaster management procedures (restructuring responsibilities within the administration, creating the disaster management cell within the administration). In the new disaster management plan decision-making competencies were streamlined to minimize response times and effectively make use of existing resources in case of disasters of “exceptionally large magnitude”. In this case a State Executive Sub-Committee for Mumbai, chaired by the Additional Chief Secretary (Home) and the Municipal Commissioner, will take over the coordination of disaster relief measures of different agencies, including municipal and state agencies as well as the National Defence Services (Army and Navy).

3.7. Efforts for resilience and spatial knowledge construction

The 2005 Mumbai floods initiated a series of actions by the authorities with the help of various private institutions and collective action by the people. Use of information and communication technology (ICT) in mitigation and management of disaster became an important part of planning processes at local, city and regional level. As the loss for the city economy was estimated to be around $100 million (UNICEF, 2006; without pages) in just two days, efforts were made to minimize future losses caused by floods. Besides the measures described in section 3.6 ICT for disaster mitigation and management has been set-up to be used in Mumbai for disaster management. Technically these have been designed in a way, that even in case of a longer black out, main communication channels can be maintained through stand alone battery systems at various locations in the city.

In the case of Mumbai the construction of local knowledge along with published knowledge and use of ICT for use in disaster risk reduction was very important. “A state mode of dealing with the problem to a societal mode of handling them, with the inclusion of the state” (Baud, Pfeffer, Sydenstricker, & Scott, 2011: 2) came into being in handling the floods in Mumbai. Along with the University of Kyoto, the Japanese Aid Agency the Greater Mumbai Municipal Corporation (Brihanmumbai Municipal Corporation – BMC) used local knowledge on the flooding and its impact on local communities in various slums (School of Planning and Architecture, New Delhi, 2009). This information was collected through surveys in flood affected areas by BMC and an Indo-Japanese research team. Spatial knowledge, in terms of adaptation/mitigation strategies were developed through the use of ICT, especially mobile phone technology (Meier, 2008) and informing local citizens about weather variations in the city and potential flood zones. SMS are sent to all mobile devices, which are connected to the mobile network in cells in which flooding is expected. Additionally BMC uses the networks/data bases of different institutions (e.g. the social media accounts or the information networks of companies, such as banks or of NGOs) to communicate about impending inundation events. The high coverage of mobile connectivity and user ratio of social media in Mumbai (cf. Department of Telecommunications, 2014, Ibrahim, 2009) ensures a good coverage of the population through these measures. This approach of spatial knowledge distribution became a unique model, which later was replicated several times in other potentially disaster affected areas, such as Orissa, Andhra, and Tamil Nadu.

For the first time, the multi-scalar governance system (Barnett and Scott, 2007) was used and integrated systematically to address issues of disaster. After the 2005 floods a new committee was established to assess Mumbai's flood preparedness each year prior to the onset of the monsoon. The Chief Minister of Maharashtra State heads the pre-monsoon Disaster Committee and the Municipal Corporation Irrigation Department and Urban Development Department of the Government of Maharashtra work in tandem to forewarn the people about potential critical situations for evacuation. This governance model was extended to various other stakeholders, who were roped into the system, such as financial institutions (this was important since the financial loss due to floods in 2005 was very high), educational institutions, and later to community networks. As discussed by many authors (Baud et al. 2011; Brenner, 2004; Robinson, 2008) governments, especially local governments all over the world, depend on local networks, especially economic and social networks in decision-making process. These networked decisions, especially in disaster mitigation and resilience, became a reality in Mumbai in the post-disaster period in 2005.

The delay in response by formal institutions during the 2005 flood event brought many community-based organizations in Mumbai together in developing spatial knowledge in the field of disaster mitigation and community resilience towards disaster. As Gaillard and Maceda (2009) stated, it was realized that disaster mitigation and resilience had to involve local communities and be “people-centric” and “community-centric”, if the efforts are to be sustainable. Area-based approaches through Advanced Local Area Management (ALM) committees, which were set up earlier and used for waste management, were utilized to create awareness about disaster at the local level thereby making the spatial knowledge construction and dissemination easier. The BMC informs ALMs through its ward offices about possible inundation events in advance, asking them to distribute the information in their respective neighbourhoods. Additionally, flood area prediction, depending on the amount of rainfall, has become more precise with the implementation of specialised software donated by the Japanese government. This GIS based software enables area-wise prediction of flood prone zones, once information about the extent of rainfall is fed into the system. BMC engineers along with Irrigation department engineers were trained on this flood management software in Japan during a capacity building programme. Both, the ICT tools provided by the Japanese Government and the involvement of ALMs together make it easier to predict impending disaster and to take mitigation efforts based on early warning systems.

Developing spatial knowledge through multiple sources in the post-disaster period, especially through participatory knowledge construction at the local level, and dissemination of the same through community, social and financial networks enabled resilience building and mitigation efforts easier for BMC. Though it was considered costly and time consuming, the mapping efforts at micro zone level and the ability to use them through capacity building at the local level has enabled local authorities at the ward level to be prepared for any disaster and respond to them immediately. Use of Community-Based Disaster Risk Reduction (CBDRR) by BMC, integrated both bottom-up and top-down disaster risk reduction by integrating traditional and scientific knowledge (Gaillard & Maceda, 2009).

4. Discussion: understanding and visualizing (mega-urban) risk complexity

The findings from the literature review, the newspaper analysis, the household survey and the in-depth interviews with lay people and experts on the Mumbai floods reveal the complex genesis of a disaster event in a megacity: The interconnection and interaction of different factors, causes, drivers and actors and their complexity of interdependences is visualized in a comprehensive diagram (Fig. 4). Tracing back some of the primary risk factors' root causes, makes it possible to reveal the complex configurations (i.e. the multiple linkages and feedback mechanisms), which are adding to the multi-dimensional risk of mega-urban floods: 1. The physical event of an unprecedented rainfall affecting distinct areas in the city differently was nothing but a starting point. 2. Lack of capacities of the municipal corporation to maintain the existing drainage network and to organize regular waste collection, for example, reduces the drainage network's capacity. Thus, administrative deficits and the citizens' way of dealing with this (waste disposal in the nullahs) influenced the secondary risk factors that constituted the disaster setting. 3. This human, in this case government-based, causation coincided with another, complex and localized spatio-social setting, namely the historic evolution of synergetic transformation of natural environments by society, i.e. an urban landscape vulnerable to inundation. This creation of an artificial landscape by different actors resulted in another subcomplex of factors in which land sealing, vegetation decline, an insufficient drainage system and changing discharge patterns interact. 4. On a smaller scale, the settlement of people with different incomes (especially the urban poor) in the Mithi river's flood plain was substantially – but in locally different ways – adding to the risk by exposing them to the flooding risk but also by narrowing the river bed and the flood plain. This has to be seen in the larger context of marginalization processes, which structurally result in poor people residing in more disaster-prone and less healthy locations. 5. Further amplifying factors, e.g. lack of information due to insufficient judgement of the situation by officials which led to inappropriate decisions being made and lacking response capacities (human and technical), further aggravated the situation. 6. Infrastructural deficits resulted in delays in delivering disaster relief in affected areas, and the failure of communication systems hindered the coordination of disaster response forces. All these factors together (risk complex) resulted in a multidimensional disaster with its specific effects. In addition, other factors, that only became relevant once the disaster had set-in, resulted in secondary risks and the development of risk chains and cascades (Fig. 4).

From a Complex Adaptive System (CAS) perspective, one can state, that the resilience of the mega-urban system, being a social-ecological system consisting of built infrastructure and society helped the system to return to functioning within normal parameters soon. In this, informal social networks turned out to have become an important factor. Some subsystems did not return back to their earlier state of functioning quickly, for example the heavily affected slum communities whose development paths were disrupted. And also the city's disaster management structure underwent change and restructuring during the system's recovery period. Community-Based Disaster Risk Reduction (CBDRR) also enabled the empowerment of excluded communities, especially those living in vulnerable areas, to integrate with the risk reduction measures. Use of ICT has enabled the BMC to forecast and disseminate knowledge to local levels within a short time to mitigate disasters and minimize their ill effects. Thus, the aftermath of the 2005 flood has brought forward maps and enabled local administration to use technology-friendly and more 'people- and community-centric' communication during disaster more than ever before.

Since new warning systems are in place and the disaster management structures have been reorganised, the risk complex has been altered. The next flood event will occur in a reorganised Complex Adaptive System. This change in the city's preparedness can be interpreted as successful utilization of social memory, which „has been defined as the arena in which captured experience with change and successful adaptations, embedded in a deeper level of values, is actualized through community debate and decision-making processes into appropriate strategies for dealing with ongoing change. Social memory is important for linking past experiences with present and future policies" (Folke, Hahn, Olsson, & Norberg, 2005: 453). This is also evident in the reaction to the heavy rainfalls the city received in June 2015. With 243 mm within 24 h, this event was the most severe torrential rain the city experienced since the 2005 event (The Hindu, 2015). Reports in different newspapers show on the one hand that the city is relatively better prepared – even if the effects on daily life are still severe and officials have been criticised heavily. On the other hand the 2005 flood event is referred to in most of the reports, showing its importance as a collective social memory (DNA, 2015; The Hindu, 2015; Hindustan Times 2015).

Some changes in the disaster risk complex have partly moderated the primary effects of flood events and most probably also helped to stop the evolution of risk chains and risk cascades. From the expert interviews and the analysis of the newspapers we can definitely state, that the management of annual flooding events has been improved: nullahs are blocked less often and areas, which are often inundated, are now quickly cleared of water, since local pumps have been installed. However, there are also doubts about Mumbai's disaster preparedness. First, some of the infrastructures created, are not maintained as good practice would demand; second, many of the measures announced have not been finalised (especially the renovation of the city's storm water system) and third, informal practices prohibit planning and applying measures

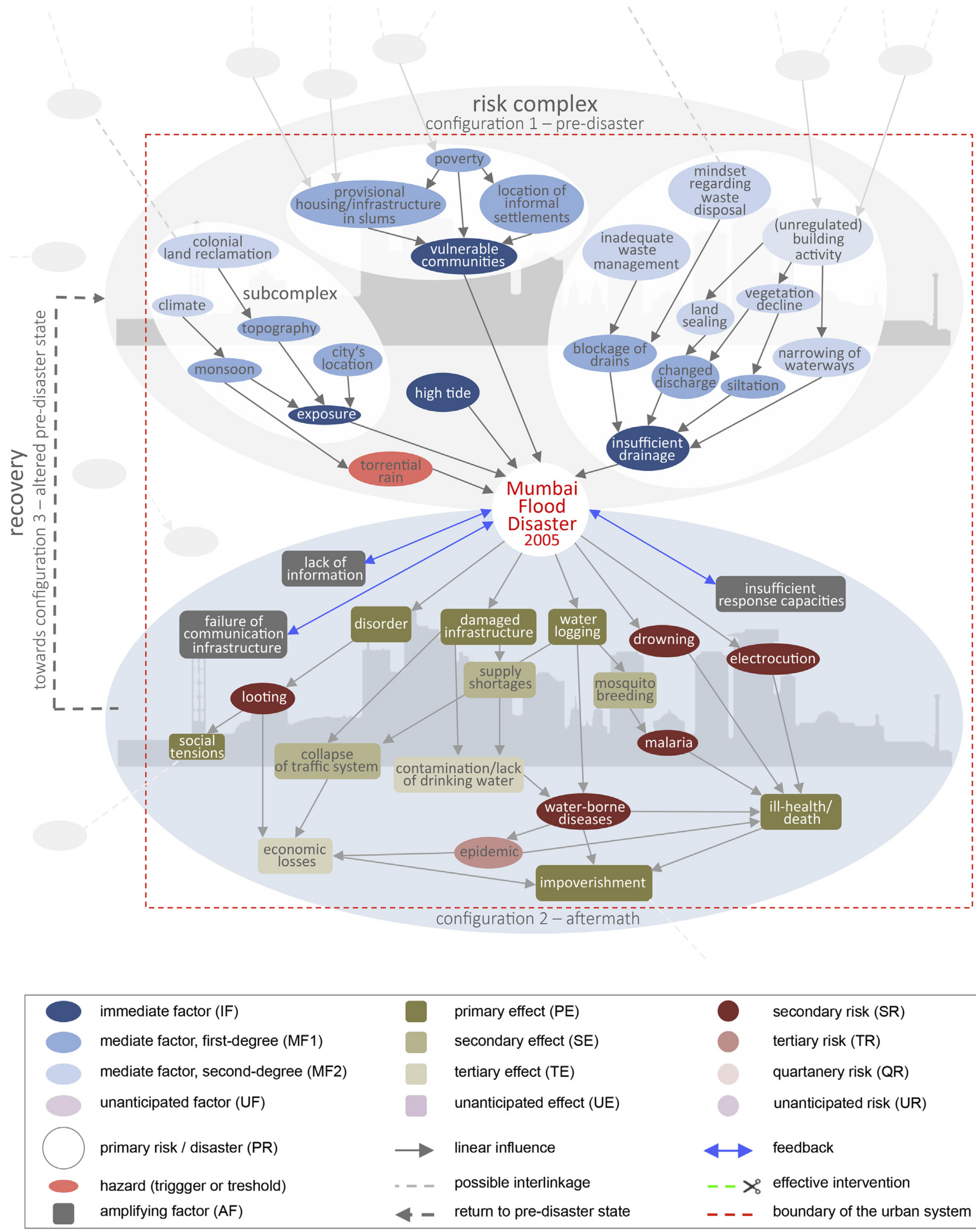

Fig. 4. The Mumbai 2005 flood event from a CAS perspective.

in the parts of the city in which informal practices dominate, and third, investments have been channelled to increase the preparedness for flood events, leaving aside the necessary measures for other risks (earthquakes, fires, epidemics etc.).

5. Conclusion

In the literature, unprecedented levels of complexity have been identified as distinct feature of megacities (e.g. Parker, 1995;

Kopfmüller et al. 2009). We have therefore developed a framework, which looks at these "global risk areas" from a CAS perspective. Our analysis of the 2005 flood event in Mumbai based on this unique perspective demonstrates that this provides added value for a more comprehensive view on (mega-urban) disasters. The framework developed in section two (Fig. 1) and its application in the context of the Mumbai flood (Fig. 4) can be read as a visualised "map" of the connections between the various factors influencing each other. It emphasises the links between the different elements of the city as a system and the potential amplifying or moderating feedback mechanisms. Thus it makes the risk complex in which disasters can occur better understandable and illustrates which effects a disaster can have either directly or indirectly through risk chains and risk cascades. From our point of view this perspective allows for a better understanding of the flood risk, since it goes beyond the analysis of the symptoms. Instead, the CAS perspective aims at tracing the mediate risk factors and the root causes of disasters in urban areas. Even if some of these root causes cannot be modified, it is important to actively take them into consideration in risk governance. However, the application of CAS/resilience-theory by governments does not go without critique. Welsh (2013) critically states that the CAS perspective, emerging from resilience theory, places disasters in a post-political sphere and has the potential to be exploited by neoliberal governance regimes: The strength of communities to prepare for the unexpected in this logic would mean less responsibility for the government but place the burden on the community. In contrast, our argument is that a CAS perspective should help decision makers to enhance their understanding of the genesis of disasters and should encourage to pro-actively include social memory.

The meta-level mapping of risk factors allows for a next step, which would then be the actual mapping of the location and measuring/qualitative description of risk factors, their connections and dynamics. This would not only allow for identifying zones of high risk but also draw attention to spatial proximity of vulnerable structures and populations and to understand them and their complex mutual interferences in their specific local setting. Thus, identifying possible connections, amplifying factors and anticipating spill over effects (risk chains, risk cascades) can be visualized and understood based on an empirical basis. Mapping risk factors in Complex Adaptive Systems can increase the understanding of connections and feedbacks (dynamic mapping of processes) and a mapping of vulnerable structures and population groups would be beneficial for risk governance. A non-hazard-centred view (i.e. not only focussing on floods, but emphasizing the embedding (risk complex) in which a disastrous flood can occur) on the connections and feedbacks between specific system elements would be a next step. Such an altered perspective allows for increasing preparedness for and the management of unexpected events or events of unexpected magnitude. If mega-urban risk governance and disaster management are based on a systemic understanding of complex risk, risk cascades and risk chains, they can be modified much easier to respond to hazards more effectively.

A challenge though is the mapping of resilience factors, especially "soft" non-technical aspects such as social capital. It became evident in the Mumbai study that the 'state dominated government structures' seldom consider 'social capital' in knowledge construction and decision-making processes and largely exclude social networks and other informal assets. The focus on mostly technical and quantitative solutions leaves (spatially bound and complex) knowledge unused. As the application of CBDRR methods proves, communities know a lot about past events – and this knowledge can be activated by participatory mapping for risk assessments. As of now the utilisation of this specific spatial knowledge by urban planners and disaster risk management experts remains improvable and their understanding of the spatiality of complex spatio-societal interconnections remains in an early stage. One reason is that complex structures, processes and actors are not taken into consideration adequately, which might be solved by visualisations like those proposed here in figures one and four. The high potential of informal institutions and self-organisation processes, which is characteristic for urban settlements in the LMIC, therefore remains unused. New forms of multi-layered risk- and disaster governance should therefore take these informal structures and actors into consideration.

Spatial knowledge and its visualisation can be an important foundation for new strategies, if it is 1) not limited to the scientific-technical knowledge of "experts" but includes also "social memories" and 2) depicts the complexity that constitutes the (potential) disaster setting. Our case study did not primarily aim at understanding spatial construction of knowledge, but the results we produced with our CAS approach informs about the understanding of spatial knowledge production. The joint efforts in the aftermath of the flood event in Mumbai in 2005 illustrate that alternative approaches towards governing mega-urban risk, based on alternative mapping methods, can offer serious benefits for formal risk governance structures. Especially the utilisation of social memories and an understanding of disasters rooted in the complexity theory provides an important, yet not fully utilised source of (spatial) knowledge for risk governance.

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ExIMum0003: Expert interview October 7th 2010 with a representative of the Municipal Corporation of Greater Mumbai.
ExIMum0011b: Expert interview 27th October with a representative of the Mithi River Development and Protection Authority.
ExIMum0013a: Expert interview November 5th 2010 with a researcher.
ExIMum0015: Expert interview November 14th 2010 with a representative of the Municipal Corporation of Greater Mumbai.
ExIMum0017: Expert interview November 22nd 2010 with a representative of the Mumbai epidemiology cell.
PCIMum0002: Interview with a resident in Shastri Nagar on November 7th 2010.